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ABSTRACT

Any effort to change a complex social system should begin by constructing models and simulations of the problem and its social context. These will increase the likelihood of long-term success, decrease the chance of unexpected negative side effects, and help conserve scarce national resources. Models may be of three types: (1) prose models--which are descriptions and theory-statements that attempt to explain the structure and dynamics of the factors affecting the problem within its setting; (2) structural models--which use a variety of symbol systems to represent the elements and relationships affecting the problem; (3) dynamic models--which are built upon the other two but have the characteristic that they can demonstrate problem-critical behaviors of the system repeatedly over an extended time period. Modeling and simulation techniques have strengths and weaknesses, and techniques may be combined to provide the best insights and approaches to practical social problems. (Author/DAG)

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Modeling and Simulation

Gus Root

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Modeling and Simulation

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. . . and the Prime Minister said,

"Only 76% of our men and 57% of our women are literate. Literacy rates are the lowest in the rural, agricultural areas, and among the poor, the under-educated and the under-employed. Your task is to plan and conduct a campaign to improve literacy rates among our poorest and most needy people."

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How should we approach such a task? Where should we begin?

There are at least two different types of approaches to this kind of a social problem, and it is important to look at and understand the strengths and limitations of each:

1. The "immediate-action" approach; We could study and learn from the experiences of those who have worked on literacy problems in many different countries around the world, and act upon the very best recommendations that fit our situation, or
2. The "analytical" approach; We could perform a detailed analysis of the society in which literacy appears to be a primary problem, identify the main inter-acting factors which both enhance as well as hinder literacy in that environment, and find those places in the social system where small changes would be most likely to produce long-term and lasting improvements, with the smallest number of undesired and unanticipated negative effects.

For those who choose to follow the first (immediate-action) approach, there are many reports available and many persons with a wealth of

practical and useful recommendations. This is the approach usually taken by those who face an urgent problem and feel compelled to take quick and effective action. This approach may lead to enough success to encourage increased effort.

For those who choose to follow the second (analytical) approach, there are only a limited number of reports on systematic planning in a particular project area, and a small number of persons with experience who can make specific recommendations on techniques for analysis-based planning. This is the approach usually taken by those who are deeply concerned about the use of scarce resources (money, talent and time) in problem areas where so many efforts have had limited success, and occasional unexpected difficulty. Often this approach leads to cautious progress in many related sectors of the social environment.

Regardless of the basic orientation a communication planner brings to the task, most would agree that a certain amount of analysis should precede action -- it is only a question of the amount and type of analysis. At the same time that analysis is started, it is also advisable to gather the available information in a project area (literacy) and get to know those who have worked in that area.

So, the beginning of any project is a busy time. The main theme of this paper is, "Begin any effort to change a complex social system by conducting models[1] and simulations[2] of the problem and its social

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1. Model. A representation of selected characteristics of some situation or problem of interest, e.g., a description, diagram or scaled-down replica.

2. Simulation. An activity in which a model is operated (run, played), with the expectation that its performance will duplicate (simulate) certain critical features of the situation which is requested by the model.

context; they will increase the likelihood of long-term success, decrease the chance of unexpected negative side effects, and help conserve scarce national resources." From this point of view, the wisest approach may be a combination of the two approaches suggested above (analysis and action). It would be well to wait until the completion of the first (modeling and simulation) before acting upon any recommendations from the second.

The following sections of this paper will introduce and illustrate a variety of modeling and simulation techniques, and will try to indicate the strengths and limitations of each - as well as to suggest how several techniques, used in combination, may provide the best insights and approaches to a practical social problem such as the reduction of inequalities in literacy rates.

Notes on Changing Social Systems

From the "systems" point of view (see Lyons earlier in this Sourcebook), every social event is the result of the interaction of a large number of cause-effect relationships, in which each "cause" is itself influenced by the "effect" it produces. Thus, to introduce a new "cause" into a social system (such as an effort to improve literacy) with confidence that it will produce the "effect" we want (an improved distribution of literacy and social development) with the fewest negative side-effects (migration of the illiterate to cities and social erosion), we must understand the dynamic structure of the many interactions which are inter-dependent in their influence on literacy and social development.

But the human mind is severely limited in its ability to perceive and inter-relate all of the complexities of a social system and, from this understanding, predict the systems response to a change effort. A developing society includes many inter-connected sectors (economics, education, agriculture, communications, etc.) with many feedback loops and time delays between an action in one sector and its reactions to other sectors (and, of course, the subsequent effect back upon the original action). The human brain cannot take in, process and act upon an integrated understanding of all of these complexities without the use of some outside-the-brain assistance. This assistance usually comes in the form of theories which describe these complex relationships, models which represent these networks of cause-effect loops, and simulations which imitate the most important behaviors of these systems.

Figure 1 suggest that these kinds of "aids to thinking" progress from verbal or "prose" models (such as descriptions and/or theoretical statements), to representational or "structural" models (such as diagrams and charts), and finally to simulations or "dynamic" models (such as models which operate within wind-tunnels or computers, and human simulation-games).

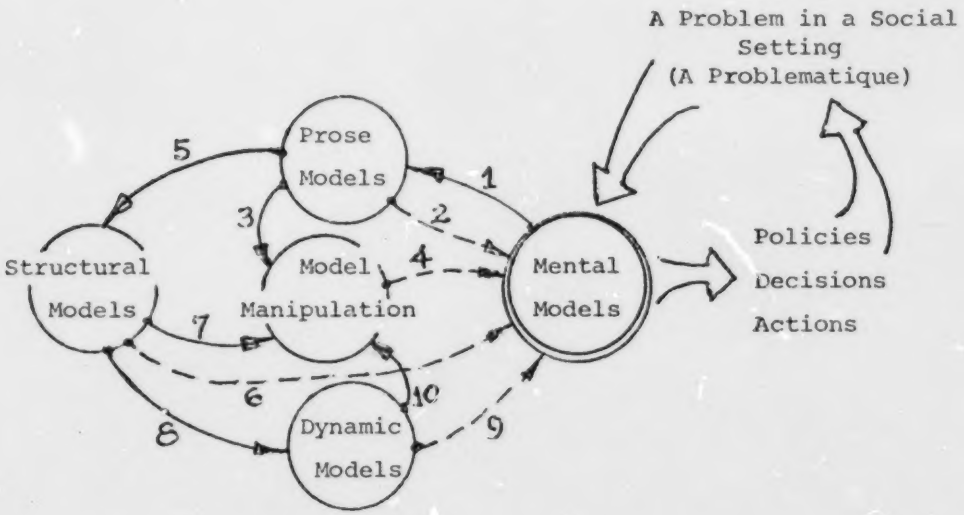


Fig. 1. A representation of the manner in which successively more complex models can enrich understanding (our mental models) which determine the policies, decisions and actions we undertake.

The sequence of lines in Figure 1 suggests both (a) the successive stages if model building and the enriched understanding that can come from each successively more complex stage, and (b) the organization of the following sections of this chapter. A brief

review of these basic ideas may help to interpret the lines in Figure 1 and, also, give an introduction to the remainder of this chapter.

Line 1: Initial efforts to understand a problem and the situation within which the problem is embedded (the problematique) usually lead to PROSE models, such as descriptions, special vocabularies, scenarios, operational definitions and theoretical statements. PROSE models are discussed in Section 1.

Line 2: New information and understanding can come from the process of defining, describing, talking about and arguing the characteristics of the problematique. A fruitful outcome of such PROSE models is an enrichment of the MENTAL models which provide the basis for action.

Line 3: There are special techniques for manipulating PROSE models, which, in turn, can lead to

Line 4: further enrichment of our MENTAL models.

Line 5: Beyond PROSE models, additional techniques have been developed for the construction of STRUCTURAL models which portray, graphically, the relationships among the critical components of the problematique (as identified and defined in PROSE models). STRUCTURAL models are discussed in Section 2.

Line 6: The process of developing STRUCTURAL models often leads to new insights (enriched MENTAL models) in those who participate. Experience suggests that these new understandings lead to enriched PROSE models which, in turn, aid in the refinement of the STRUCTURAL models.

Line 7: Techniques for manipulating STRUCTURAL models can lead to

Line 4: even further understandings.

Line 8: Beyond STRUCTURAL models, special techniques can lead to the development of DYNAMIC models which imitate or simulate the critical performances of the problematique, as have been expressed in both PROSE and STRUCTURAL models. DYNAMIC models are discussed in Section 3.

Line 9: The development of DYNAMIC models leads to a greater understanding of the problematique - and this usually requires frequent cycling through the earlier stages of PROSE and STRUCTURAL models.

Line 10: Manipulating DYNAMIC models can lead to

Line 11: still further enrichment of our MENTAL models, and this is the continuing goal of all modeling effort.

The following sections of the chapter will describe each of these three types of models, suggest some simple techniques for constructing models of each type, and will give illustrations of the both procedures and results from several modeling projects.

Some Preliminary Definitions

Simple definitions and illustrations of concepts which are central to the ideas of this chapter are relatively easy to provide. Slightly more complex descriptions and illustrations will follow. A full understanding of these concepts can only be developed by those who read widely in the literature of this field and participate in a variety of modeling projects. (That is to say, it seems reasonable to predict that a reader's MENTAL models of these concepts will also develop through the processed suggested in Figure 1.)

The purpose of this chapter is to introduce these ideas and provide sufficient information that practical, non-expert kinds of people would be able to build simple but useful models (of all three types), and use them as aids to decision-making in important, practical situations.

Models: are simplified representations of selected characteristics of some situation of concern (some problematique). Social problems exist within a complicated network of factors which produce the problem symptoms. This network is usually sufficiently complicated to obscure the basic structure of the cause-effect relationships within which the problem is embedded. A "model" attempts to simplify this situation, and to abstract the most important characteristics of this network. Common examples of "models" include:

- verbal descriptions,
- drawings, maps and charts,
- toys, replicas, and scaled-down copies, and
- sets of equations and computer programs.

Simulations: are activities in which models are "operated" or "played" in hopes that the model will imitate (simulate) the critical performances of the situation (problematique). The purposes of simulations may vary to include education, research, design improvement and/or the exploration of the probable effect of different policy decisions. Common examples of simulations include:

- model airplanes that "fly" within wind tunnels in order to observe and improve their performance characteristics;
- business games that are based upon models of the market environment, and which are conducted to train executives;
- computer models which are "run" under a variety of initial conditions to observe the probable effect of different allocations of resources among the sectors of the model.

Decisions: are the action-commitments of resource-assignments of individuals or groups when faced with a situation for which there is no existing agreement, routine, or habit. Decisions are choices made after an analysis of the implications of a set of alternative possible commitments or assignments. The purpose of a decision is to respond to the changing demands of a situation in a planned or deliberate manner - rather than reacting on the basis of habit, tradition, or whim. Examples of decisions are:

- the selection of a particular type of telephone system after the analysis of several proposals and a set of goals for the region to be served;
- the allocation of resources among education, agricultural and literacy programs according to a formula, rather than based on the rhetoric or social power of the persons requesting support;

- the establishment of a national information-and-news bureau, rather than leaving the news services in the hands of private-profit corporations or international agencies.

Organizational Note:

The body of this chapter is divided into three sections:

Section 1: PROSE Models

Three examples of PROSE models will be presented.

Section 2: STRUCTURAL Models

Two examples of STRUCTURAL models will be discussed.

Section 3: DYNAMIC Models

Two examples of DYNAMIC models will be reviewed.

The paragraphs within each section will be numbered, e.g., 1.2.1 or 3.1.2, to help in keeping track of the flow of ideas within sections.

1.0. Beginning with PROSE Models

In building any model, it is as though we try to express all we know and believe about the system of concern (the problematique) and represent that current knowledge in the model, thus leaving our minds free to think about other information or our next activity. If we can bring back this model whenever we need it, we won't have to remember and reconstruct all of that information every time we need to think about that problematique. In this way, models act as temporary storage for large amounts of organized knowledge and are very useful aids to our thinking about social problems.

The process of model building usually begins with an awareness that something is not quite as hoped, anticipated or expected - it begins with a wonder, a worry or a woe! This "awareness" stage (Figure 2) is usually followed an attempt to define the problem and its context (which we are calling the "problematique").

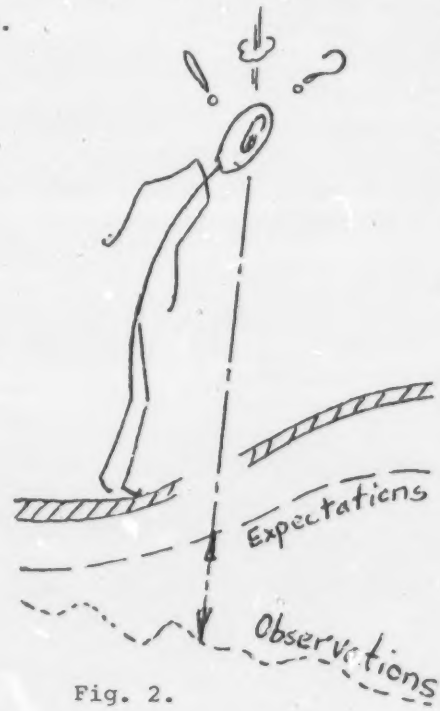


Fig. 2.

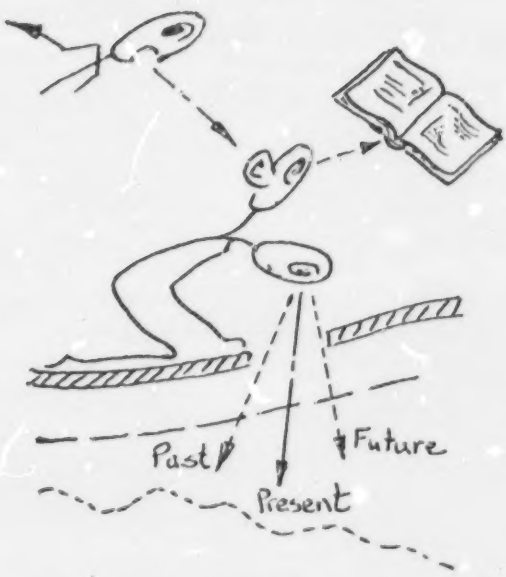


Fig. 3. An analysis of the problematique.

The analysis phase of model building finds the individual (or group) examining the characteristics of the problematique over time. The analyst seeks to determine what has happened, what is happening now, and what is likely to happen if the current trends continue (Figure 3). It is not enough for a single individual to work this out alone, usually, he asks, listens and reads.

The analyst's concerns, observations and expectations are often expressed in words (his MENTAL model is transformed into a PROSE model) as he talks with others and writes about his preliminary conclusions. There are many advantages to be gained from the preparation of PROSE models:

1. Public PROSE models can be examined by others whose perceptions may be different, thus leading to refinement, correction and confirmation.
2. PROSE models can include a larger number of elements and relationships that can be handled within a single person's MENTAL model.
3. Written PROSE models can be examined in a non-sequential manner, without the danger of losing those elements of the model which are not currently being examined.

4. Preparation of PROSE models demands that concepts be expressed with a degree of precision and organization which is not required by MENTAL models, whose "fuzziness" may not be apparent until the precision of language and the structure of formal presentation are imposed upon those concepts.

A number of techniques have been developed to facilitate the preparation of PROSE models. Because the PROSE model appears to be the first step in any modeling effort, it is appropriate to examine a few of these techniques in some detail.

1.1. Brainstorming. The essential characteristics of this technique center around the group production of a full range of ideas (from the immediately practical to delightful flights of fantasy) under conditions of acceptance and the absence of criticism.

1.1.1. The technique is usually to:

a. Bring together a relatively small group of persons (4-14) with knowledge and interest in the problem and its context.

b. Introduce the topic in its most gross and simple form.

c. Present the rules for working together on the problem, such as:

- Each person is encouraged to contribute any idea which may be relevant to the topic, regardless of how strange or absurd, and the contribution will be accepted and recorded.
- Negative or critical judgments of others' contributions are to be withheld (and small fines may be extracted from anyone who criticizes another's suggestion).

d. Have a recorder write each contribution publically on a chalkboard or easel pad, to keep all information before the group.

e. Introduce the next level of problem complexity and ask individuals (working alone) to simplify, cluster and organize the items, to select the most promising items according to criteria provided; and to expand or elaborate upon the previous items to account for the new information provided.

f. Repeat Steps c, d and e, above, as many times as is fruitful, with additional information supplied at each iteration. This process may be continued until the group has come to some acceptable degree of completion of the tasks of analysis, model definition, examination of alternatives, and selection of a preferred approach to problem resolution. How far the process is carried may depend upon the skill of the leader and the patience of the participants.

1.1.2. An Example of Brainstorming. A group of educators was concerned about ways to improve the effectiveness of Community Education (locally initiated education activities designed to enhance citizens' ability to work together for common good). Because of strong national interest in stimulating these local activities, agencies have been established at federal, state and regional levels to stimulate and support community education with money and programs. Professional organizations have been established to encourage the professional development of the persons involved in community education. But there is little agreement on the characteristics of the networks which inter-relate all of these people, organizations and activities, and there is even less agreement on which of these elements and/or relationships would be most important for the further development of the network's effectiveness.

Four community educators came together for a two-hour brainstorming session in an office with a chalkboard. A consultant (not a community educator) led the group to create a long list of the factors that affected and were affected by community education (CE), or the causes which influenced CE, and also the effects produced by CE. In the second round of the brainstorming activity, individuals clustered and categorized these factors in order to simplify the list that had been generated. A set of factor-clusters was developed that all agreed was adequate to account for the major elements and relationships within the CE-network. In a third 'round', the participants were led to identify the magnitudes and directions of the major influences among these factor-clusters within the network, with a resulting PROSE-model that expressed the agreements among their individual perceptions (and de-emphasized the disagreements). Spontaneous expressions of surprise and pleasure followed this exercise, as a result of being able to see actions that could be taken that all felt would be constructive and each felt had a high probability of being effective than the individual ideas which did NOT get group confirmation.

1.1.3. Advantages of the technique include:

a. A high level of emotional involvement in the problem and the group effort (if the setting has been adequately planned and the activities are directed with skill and good humor). This can lead to wide acceptance of the outcomes of the process.

b. Possibilities that might initially seem absurd can be given serious consideration, and may be developed and adopted when they might not have been considered under other conditions.

c. The contributions of persons with widely differing backgrounds can be focused and integrated within a short period of time.

1.1.4. Disadvantages of this approach may arise from:

a. The personal characteristics of participants, among whom there may be persons with charisma or political power who may attempt to push for their own ideas, or others who are shy or socially unskilled and whose ideas may not be heard or recognized. These difficulties may be overcome (or minimized) by skillful group leadership, or by the use of external consultants with sufficient prestige to moderate the social interaction and permit the group to focus on the problem.

b. The technique may appear to encourage trivial and ridiculous thinking about serious problems. This criticism is most likely to be raised by those who feel strong pressures for immediate action, based upon solutions that have been "proven" in many similar situations. It is very difficult to convince such "practical" people of the advantages of exploration and analysis, and it is sometimes constructive to assign such persons to the task of getting to know professionals who have been effective in other situations and the approaches they have used. That information could also help to enrich our verbal and mental models.

1.2. DELPHI. The essential characteristics of the DELPHI approach to the construction of PROSE models center around the responses of a large number of persons to printed materials through successive 'rounds'

of questioning and giving feedback to each participant about his/her responses compared to all other participants.

1.2.1. The technique usually involves:

a. Identifying a large number of persons with various types of expertise relative to the problem under consideration, and securing their agreement to participate in an extended series of questions-feedback-questions.

b. Asking each participant to identify/describe the most important characteristics of the problem, influences that affect it, and possible future conditions relative to the problematique. Each person is asked to respond individually.

c. All responses are analyzed and organized to identify similarities and differences among sub-groups of the participants.

d. Each participant is given information on all other responses including the means and deviations of various sub-groups, and shown his/her response relative to the others'. The individual is asked to consider modifying the initial responses or justify any differences observed. Additional information may then be given to the individual and new questions presented.

e. Repeating the above steps until the various positions have been clarified and defended, and the purposes of the analyst have been achieved (or the patience of the participants exhausted).

1.2.2. An example of a DELPHI approach. A School of Social Work wanted to design an undergraduate curriculum derived from the best thoughts of a wide variety of administrators, scholars and practitioners within the field of Social Work. The first rounds of the DELPHI process were used to identify the categories of persons who should be involved in the study, and the specific persons within each of these categories. In the successive rounds of the study, broad subject areas were identified, specific details were developed within each broad area, and the appropriate balance of emphasis among the topics was established. At each step of the process, the major differences of opinion were identified and defended or critized. The School's responsible faculty was immediately involved in each step of the process, and was able to both observe differences between its perceptions and those of respected colleagues, as well as significant differences within its own body. The outcomes of the study was a high degree of confidence that the resulting curriculum was the best that could be devised at that time, an increase in the reputation of the School within the profession of Social Work, and a new appreciation of the faculty for the differences and agreements among its own members.

1.2.3. Advantages of the technique may include:

a. The involvement of a large number of persons from many different disciplines and perspectives.

b. The participation of persons throughout a broad geographical area without the costs and time required to come together at a meeting.

c. The avoidance of interpersonal forces which might inhibit some contributions and give undue weight to others because of the command or charisma associated with the person supporting a particular position.

1.2.4. Disadvantages of this approach to building a PROSE model may include:

a. The difficulty of preparing and presenting questions and issues in a way that is interpreted appropriately by a wide variety of persons at some distance from the analyst.

b. Difficulties associated with the interpretation and analysis of the responses, including the question of the reliability of procedures for clustering and simplifying responses received.

c. The difficulty of maintaining the serious attention of the participants throughout the long (and sometimes boring) process of responding to many detailed items, repeatedly, over a long period of time, with minimum social interaction with other participants and the analyst.

(These difficulties can best be handled by the employment of research-trained analysts, selecting participants on the basis of their inherent interest in the problem to be studied, minimizing the time required for the study, establishing at least minimal personal contact with the respondents, giving public recognition to their participation, and building confidence that results will influence important decisions and actions - which will, in turn, influence them.)

1.3. Scenario Writing. The essential characteristics of this approach to the construction of PROSE models center around the description of

alternative possible future conditions, each attributable to a particular policy or decision on the allocation of available resources (money, time and talent).

1.3.1. The technique usually involves:

a. The identification of groups of persons who support particular positions with respect to a problem or decision which will affect a large number of persons or groups.

b. The preparation of a written description of each group's anticipated outcomes resulting from the decision it supports, including a logical analysis of the steps anticipated from the decision to that anticipated future.

c. The analysis of all "scenarios" by a select group of participants and consultants, to identify the critical descriptive-dimensions of each scenario.

d. An agreement among all groups to rewrite their scenarios in a common format, organized to include consideration of the significant descriptive-dimensions, and edited by external consultants to assure a common level of rhetoric and language usage (to remove advantages or disadvantages for any one group due to the differential verbal skills of its members).

e. An agreement among all groups of the value-dimensions on which a decision should be based when choosing from among the alternatives. A variation of the "brainstorming" approach described above, can be used to identify these value-dimensions, and establish a relative weighting among them (see, also, the illustration which follows).

f. All scenarios are distributed and studied by each group.

g. The groups then come together to evaluate all scenarios according to the weighted value-dimensions. Depending upon the amount of continuing dis-agreement and emotional rhetoric elicited by the need to select one scenario as the basis for action, the technique at this time may range from simple discussion to a closely organized procedure for differentially weighting the alternatives (see the example for a description of a closely organized approach).

h. Following a detailed consideration of all scenarios, the responsible decision making groups (or individual) reaches and announces a decision.

1.3.2. An Example of Scenario Writing. A moderately large organization had suffered a major disaster which all but destroyed its physical facilities. The problem facing the organization concerned deciding among the alternatives of (a) rebuilding in the same location, (b) merging with one or more other similar organizations, or (c) building new facilities in a totally different location. Groups had formed to support each of the alternatives, and each had enough power (financial, political and personal) that no clear decision could be reached without major fragmentation of the organization.

Planner-consultants were asked to assist all groups in reaching a high degree of concensus. In a series of meetings, five scenarios were prepared - one for each of the positions so strongly defended. In the process of writing and editing the scenarios, all groups came to agree upon the characteristics of the future organization which

should be dealt with in each scenario. Following this analysis, a set of value-dimensions was developed by the entire group of decision makers, as well as the relative weighting that should be given to each dimension. The process was approximately as follows:

1. In a brainstorming session, a set of seven (7) value-dimensions was established and given enough agreement that everyone was willing to proceed.
2. In a small number of 'rounds', the value-dimensions were placed in a list by 'rank order', from the most important at the top, to the least important at the bottom of the list.
3. The bottom item was given an arbitrary weight of 10.
4. The next to the last item was then assigned a number relative to 10, to indicate its weight relative to the bottom item.
5. The third to the last item was assigned a weight which placed it relative to the two lower items. This led to re-assignment of numbers to the lower items.
6. This process was continued until all items were assigned numbers indicating their relative weightings.
7. All of these "importance weights" were added; each value-dimension's weight was divided by the sum of all weights and multiplied by 1000. This computation merely converted the weights into numbers something like percentages (purely arbitrary).

A matrix was then prepared which displayed these seven weighted value-dimensions down the left side, and the five alternatives across the top as suggested in Figure 4.

Value Dimensions	Wt.	Alternative Scenarios A	B	C	D	E
1	210					
2	190					
3	170					
4	150					
5	130					
6	90					
7	60					
TOTAL	1000					

Fig. 4. A decision-oriented matrix of value-dimensions on alternative scenarios.

Each individual decision-maker was then asked to consider each row of this matrix, and distribute the number of points allocated to that value-dimension among the alternative scenarios according to his/her belief about the relative potentiality of each scenario for achieving that value. Each decision maker then publically displayed his/her point assignments (the numbers in each cell of his/her matrix). When the columns for the scenarios were summed, alternative "c" amassed more than

half of the total available points, and its total was more than twice that of any other alternative. After a long moment of silence as the group considered these outcomes, a quiet and nearly unanimous vote was taken to adopt Scenario "C" and its implied decisions. One group of participants which had been highly vocal in earlier discussions announced that it would separate from the others, and that separation was accepted by all parties with significant understanding and good-will. Action was immediately taken to implement proposal "C".

1.3.2. Advantages of this approach usually include:

a. Each participant and group has a full and equal chance to have its arguments and convictions received and carefully considered.

b. Differences between groups in terms of power, charisma and verbal skills are equalized.

c. The critical value-dimensions on which all alternatives will be judged are openly examined and given weightings that are physically determined and displayed.

d. Decision making power is permitted to rest in normally constituted authorities, but every viewpoint has the same opportunity to contribute information to influence that decision.

1.3.3. Disadvantages of this approach to PROSE models include:

a. The unequal abilities of groups to formulate and express their opinions, perceptions of cause-effect relationships, and decision criteria - despite the efforts of consultants to assist them.

b. The special skills required by the consultants to perform in this highly emotional, deadline-oriented situation.

c. The difficulties which may follow this procedure, after the decision has been made, when persons with power may take action relative to the others based upon actions they may have taken during scenario processes - and participants are usually well aware of that possibility during the experience, and may adjust their behavior accordingly.

(Although these difficulties may be insurmountable, the value of scenario writing - often in a truncated form of the procedure noted above - is very high, because of the clarification of issues that results.)

1.4. Manipulating PROSE Models. As suggested in Fig. 1, PROSE models can enrich our MENTAL models in two ways: through the procedures for developing the PROSE models, and through manipulating PROSE models after they have been developed. The discipline required to clarify and formulate a verbal description of one's perceptions can be a cleansing and purifying experience. But the benefits of PROSE models are not limited to the values of this developmental process.

PROSE models can be manipulated in ways that provide further insight. One example of such manipulation was included in Section 1.3., Scenario Writing. Multiple scenarios can be prepared and compared. Even beyond the description of the views of groups who have strong differences, another group may be assigned the task of preparing one or more "brainstorming" scenarios, or inventing some radically different alternatives, or possible futures. These procedures can force the analyst/designer to (a) identify the most important descriptive-dimensions of a good scenario, or the characteristics essential to a good PROSE Model, and (b) define the critical value-dimension to

be used in choosing one from among several scenarios.

There are several ways PROSE models can be massaged and manipulated in order to clarify and enrich MENTAL models (understanding, perceptions) of the responsible decision-makers.

2.0. From PROSE to STRUCTURE

A major step in modeling occurs when the models used are capable of including and representing a large number of elements and relationships in some compact form. Prose or verbal models have certain inherent limitations which can be overcome by using another system of symbols, other than words. Verbal models are limited in that they can only express concepts through a set of symbols which must be processed in a particular linear sequence, one word or word cluster at a time; the characteristics of an object, event, relationship or rule are not in the words or word-clusters themselves, but are developed by the observer as a result of processing the word clusters (verbal symbols) in a particular sequence. Other symbol systems have been developed which are also capable of representing and displaying factors that have been found to be critical in PROSE models - and these other symbol systems may have a number of advantages over verbal symbols (words and word clusters). Special symbols can represent directions of influence, relative magnitudes and forms of relationships, e.g., arrows, numbers, mathematical operations, which would require many word clusters to describe them. In addition, other symbols may be considerably less ambiguous than words, forcing greater precision on the symbol user (e.g., 2*A + 3.1*B is considerably more compact and precise than saying that A and B combine additively with B exerting a stronger influence than A on the combination). Also, models with this additional precision are more open to analysis, empirical testing and confirmation/criticism/change; verbal or PROSE models are usually difficult to validate or refute because of their ambiguity.

(The above discussion brings us back to a re-consideration of the purpose of models; in this paper, the primary purposes of models

are assumed to be (a) the representation of what are thought to be critical factors (elements and relationships) which account for a significant portion of the performance of the problematique, (b) the development of increased understanding of that object system and ways to represent that understanding, and (c) the guidance of efforts to work with and change the performance of that object system in ways thought or felt desired. In simpler terms, the three purposes of models are for improved conversations, research and application. As the symbol systems used in our modeling efforts become more complex, concise and precise, the possibilities for what we can do with our models increases. Thus, this second stage of model development moving from PROSE to STRUCTURAL models opens up new and powerful techniques for understanding and dealing with systems.)

2.1.0. Cross-impact Matrix Models. The essential characteristics of this technique include the production of a diagram which shows (a) the significant factors that affect and are affected by the problem of concern, (b) the directions in which some factors influence others, and (c) the relative magnitude of those influences. The intent of this diagram (matrix) is to show, visually, the relationships among the most important factors related to the problem of concern. When this structure of relationships is arrived at through group participation, it can organize and simplify the group's thinking about the most effective places to initiate design changes to improve the problem-system's performance.

2.1.1. The technique can be illustrated by the following procedures:

a. Bring together a small group of knowledgable and concerned people. Special leadership skills may be required if the group is larger than about eight (8) people and/or

there are members with special expertise in the problem area, who have social or political power relative to the others, or possess personal characteristics that affect group functions (talkative, shy, strong social needs).

b. Follow the Brainstorming procedures described in 1.1., above, identify a set of 5-12 factors which most agree are critical to an understanding of the system and its possible influence by the group.

c. Prepare a "matrix" as illustrated below,, with these factors arrayed both down the left hand side and along the top edge of the matrix. Those on the left are labeled "causes", and those along the top "effects".

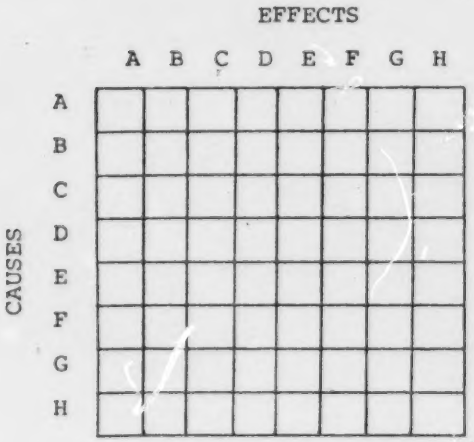


Fig. 5. A simplified illustration of a blank cross-impact matrix.

d. Each person, working individually, is asked to consider each factor as a cause (starting at the left and working across one row of the matrix) and to estimate the relative strength of its effect on each of the other factors.

They are to ask themselves, "If this cause were to increase substantially, how would that effect react?" Any of several symbols could be marked in the "cell" of the matrix to indicate the relative strength of this cause-effect relationship; a simple procedure would be to ask the participant to insert a "+2" if the influence is perceived to be strongly positive (an increase in the cause, produces a large increase in the effect), "+1" if the influence is moderately positive, "0" if there is no influence, "-1" if there is a moderate negative influence (an increase in the cause produces a decrease in the effect), and "-2" if the influence is strongly negative.

e. A large blank matrix is mounted on the wall, and the sum of the individual estimates in each cell is determined and displayed. Any large differences among group members may be discussed if there is both time and a constructive atmosphere for exploring such differences (there may be times when anonymity must be maintained for personal or political reasons).

f. The final matrix is closely examined to identify the places where the group members might initiate actions with (1) a high probability of achieving desired effects, and (2) little likelihood of causing undesired effects, even through an interconnected series of influences or second-and-third-order effects.

2.1.2. An example of a Cross-impact Matrix. A planning group in a late-developing-country was concerned with the distribution of effort within an educational materials development center (EMDC) for maximum impact upon the educational systems of the entire country. A procedure was carried out involving the members of the Planning Unit (four persons) and a succession of managers from the separate departments of the EMDC (time demands prevented them all coming together for an extended series of meetings). The procedure can best be described as a combination of the Brainstorming technique (Section 1.1. of this paper) and the development of a cross-impact matrix. A third feature of the process was a continuing effort to provide outcomes of work with the other managers when he was not present (this was done to include some of the desirable features of the DELPHI technique, described in Section 1.2., above).

a. From three sequential Brainstorming sessions, a set of critical factors related to the network in which the EMDC was involved were agreed to be:

The four major resources used by the EMDC:

A. Professional time of the staff

B. Professional competence of the staff

C. Managerial competence of the staff

D. The facilities and materials used.

The two major types of activities in the Center

E. The preparation of educational media and their distribution

F. Field work with and training for audiences

The two major classes of audiences

G. School related people

H. Government decision-makers

The major feedback mechanism

I. The amount of budget allocated by the government decision-makers

b. These nine factors were arrayed down the side and along the top of a 9 x 9 matrix; each participant was asked to indicate the relative strengths of all cause-effect relationships; their individual estimates were added, and the strongest of these were selected as the most important elements in the structure of the EMDC-education system.

c. The resulting matrix, as in Fig.6., was given to all participants.

CAUSES \ EFFECTS	A	B	C	D	E	F	G	H	I	Row Total	Combined Total
A. Prof. Time					+	+				2	5
B. Prof. Comp.					++	++				4	5
C. Mgmt. Comp.	+	+			++	++	+			7	7
D. Mat'ls, Facilities					+	+				2	4
E. Prod'n & Distrib.							+	++		3	9
F. Customer Services							++	+		3	9
G. Schools								++		2	6
H. Gov't. D.M.s									++	2	7
I. Budget	++			++						4	6
Column Totals	3	1	0	2	6	6	4	5	2		

Fig. 6. A complete cross-impact matrix.

d. The immediate outcome of this process (and the resulting matrix) was the realization that (a) this matrix did reflect the present structure more accurately than any of their preceding models (or personal thoughts), and (b) there were probably some serious weaknesses somewhere in that network which should be explored further. (Thus, this illustration will be continued following the next type of modeling to be described, Causal Loops.)

2.1.3. Advantages of the Cross-impact model arise from its requirement that the participants examine the relationships between the system's variables (critical factors) systematically, and individually, two at a time. Without some kind of structuring mechanism, most people find it very hard to concentrate on only a limited number of factors and relationships for long enough to express their current perceptions. When participants can see the entire matrix, and realize that they will be able to examine the entire structure, one cell at a time, they seem to gain confidence that this systematic procedure will permit them to express all of their ideas. Thus, the discipline of the process appears to provide a large amount of freedom.

In addition, the requirement that people work alone tends to reduce the impact of social factors which might, otherwise, give too much weight to the perceptions of those with social or political power (or, on the other extreme, too little weight to the perceptions of those without such power). If the group environment would permit it, the leader may ask each person to post the numbers in his/her matrix, so that large differences between perceptions can be discussed - but this requires a degree of openness to differences which some groups cannot provide.

2.1.4. Difficulties with this technique are similar to those mentioned above for other types of verbal or PROSE models and include:

a. Participant centered difficulties, associated with the social, political and personal characteristics of the group members. The stronger these influences, the greater the competence and status requirements of the leader in guiding the group to a useful cross-impact matrix.

b. Technique centered difficulties, associated with (1) some persons lack of familiarity with a matrix, (2) some persons inability to limit themselves to considering only one interaction between two factors at a time, (3) the subjectivity of the estimate which is based on personal perceptions, (4) the relative sophistication of some persons who perceive these relationships as non-linear and impossible to describe by a single number in a matrix, and (5) the inability of the technique to consider and display time delays between actions in one part of the matrix and reactions in another region. Most people are willing and able to construct this type of a matrix without difficulty, provided the leader appears confident and in control of the social situation, and is able to encourage participants to complete this effort in order to see its outcomes and then consider the next steps beyond the construction of a cross-impact matrix.

2.2.0. Causal Loop Models. These types of models are very similar to cross-impact models, except that the information is shown in a diagram of names and arrows. The factors are those which have been identified

in the PROSE models as described in Section 1, above (see 1.1. Brainstorming; 1.2. Scenarios; 1.3. DELPHI). The direction of each cause-effect relationship is determined in a process such as described in Section 2.1. Cross-impact Matrix. For many persons, a diagram of factor-names and arrows which show the relationships among those factors, is much more easily seen and understood than a matrix which displays the same information.

2.2.1. The technique for constructing a causal-loop diagram is:

a. A cross-impact matrix is developed, following procedures roughly described in Section 2.1.1., and shown in Fig. 6.

b. Begin most simply by selecting those factors (only 3-4 factors) with the highest totals in both the rows and the column of the matrix (Fig. 6.). Place those factors in the approximate center of a sheet of paper; connect arrows between them pointing in the directions indicated by the strongest cause-effect links in the matrix. From Fig. 6., the four most influential factors are (E) Production and Distribution, (F) Customer Services, (B) Management Competence, and (H) Government Decision-makers. These factors and their interactions are shown in Fig. 7., below.

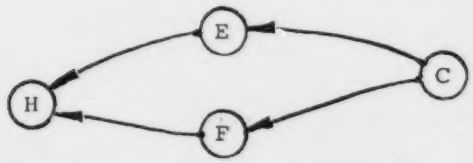


Fig. 7. The first steps in constructing a causal-loop diagram.

c. Additional factors are added to the diagram in rank order according to their combined totals. Initially, avoid adding arrows suggesting that two factors are both causes and effects for each other (include such reciprocal interaction later, only when the meanings of such mutual influence have been carefully explored). The second step in the preparation of the causal-loop would, then, yield Fig. 8., as shown below.

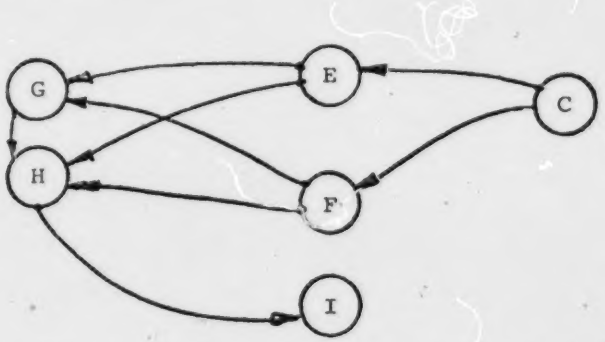


Fig. 8. An enlarged causal-loop diagram.

d. The remaining factors are added to the diagram until closed loops have been shown, stopping at the point where the diagram is both significant and still easily understood. If too many factors and arrows are combined within one diagram, it may become merely confusing, and may obscure some of the most important and fundamental causal-loops. The diagram in Fig. 9 shows all of the factors presented in the cross impact matrix, Fig. 6, yet retains a simple and easily understood character.

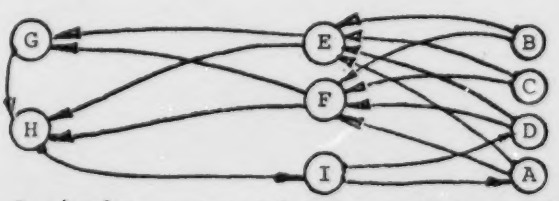


Fig. 9. A simple, yet complete causal-loop diagram.

e. To make it easy for others to understand this diagram (particularly those who may not have been involved in its development), it is desirable to replace the symbols (A., B., etc.) with the names of the factors, and to omit the circles - the intent, here, is to use the fewest possible special symbols to display the important information which has been developed. At the same time, it seems to help if the diagram has as much "symmetry" as possible and the arrows are curved to aid in suggesting the "loop" nature of the influences. Fig. 10 was only developed after considerable effort to make it easily understood by a variety of persons who were not involved in its preparation.

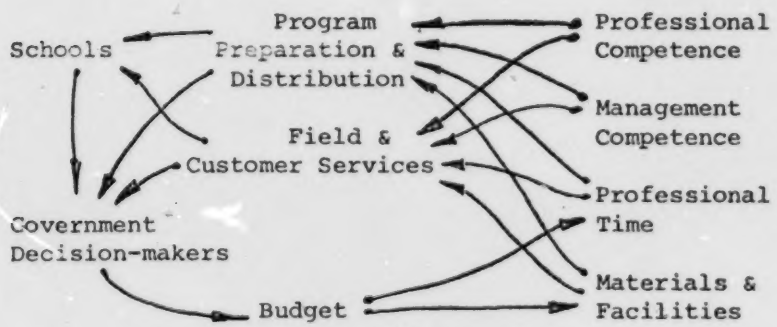


Fig. 10. A complete causal-loop diagram, adjusted for ease of interpretation by others who had not been involved in its preparation.

2.2.2. An example of a causal-loop analysis. One example had already been given, showing how the information in a cross-impact matrix was modified for a causal loop diagram. This second example will illustrate how a causal loop diagram was developed in another study, without the

construction of a cross-impact matrix.

A college was faced with a shortage of financial reserves, and was forced to reduce its support of some internal activities. Should it reduce expenses for instruction, administration or research? There were strong arguments both for and against each possible plan for the re-allocation of scarce resources. A three-phase study was conducted to (1) gather data from the four College Deans, eight department chairpersons and eight senior faculty members, (2) construct a model that attempted to show the most commonly perceived structure of the college as it influenced the effect of financial allocations on administration, instruction and research, and (3) manipulate this model in ways that might suggest the probable impact of alternative plans for readjusting the flow of resources within the college. A simplified version of the activities and outcomes of this study is given below.

a. A small planning group conducted carefully structured interviews with the 20 participants (Deans, Chairpersons and Senior faculty) to gather data on their perceptions of the goals and characteristics of the college.

b. The interview data were analyzed, categorized and simplified in order to identify the factors considered the most critical within the college, as it responded to problems, while working toward its goals.

c. Each respondent was given feedback on these most-commonly-perceived factors, and given the chance to change or add to the list.

d. Because most had indicated that "Competence of Graduates" was the central concern of the college, each respondent

was asked to place a small circle (labeled "Comp. Grads") in the center of a large sheet of paper. Considering "Comp. Grads" as a quantity which could increase and decrease, each respondent was asked to identify factors from the list which would act directly on "Comp. Grads." to cause it to rise and fall, and to show those factors on the diagram as other circles with arrows leading to "Comp. Grads." Similarly, if "Comp. Grads." was considered as a factor which influenced ("caused") other factors to increase or decrease, the respondent was asked to show those other factors as circles with arrows leading from "Comp. Grads." to those factors. Thus, every factor was considered as both a "cause" and an "effect", in order to trace out a number of cause-effect relationships and loops.

e. The study team examined all of the respondents' diagrams, identified the most commonly perceived structures, and prepared a causal-loop diagram that included the respondents' perceptions in a symmetrical and meaningful manner. In this process, three successive causal-loop diagrams were prepared, each a little more complex than the earlier one. The diagram in Fig. 11 was the most common core of all respondents' drawings, but appeared too simple to represent the complexities within the college. Figure 12 added a few details to the basic structure of Fig. 11, yet still seemed too simple. Fig. 13 added still more complexity

to Figures 11 and 12, seemed to represent most of the interactions involved in the college's dynamic operations, and appeared to be at the limit of the study team's ability to analyze.

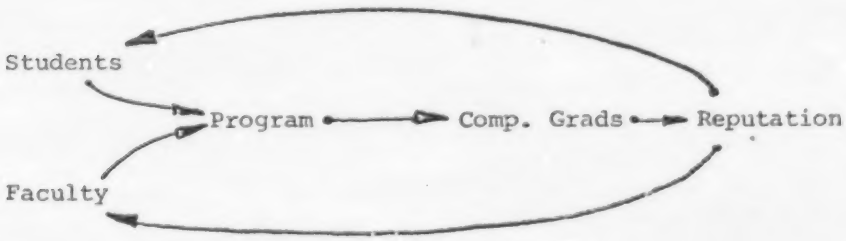


Fig. 11. A simple causal-loop diagram of dynamic interactions within a college.

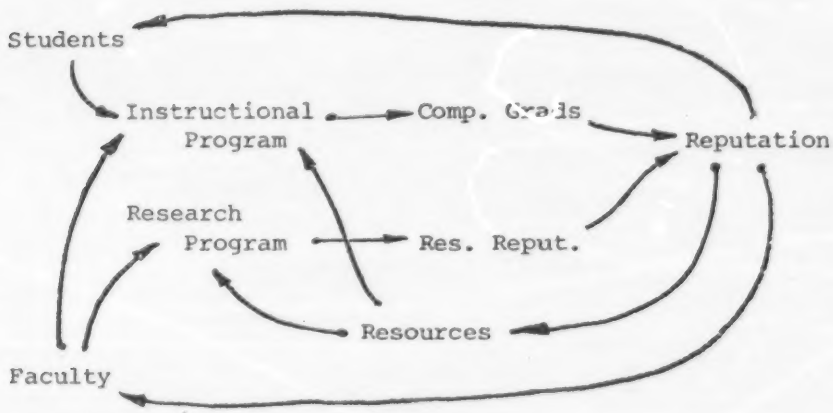


Fig. 12. An expanded causal-loop diagram of the dynamics within a college.

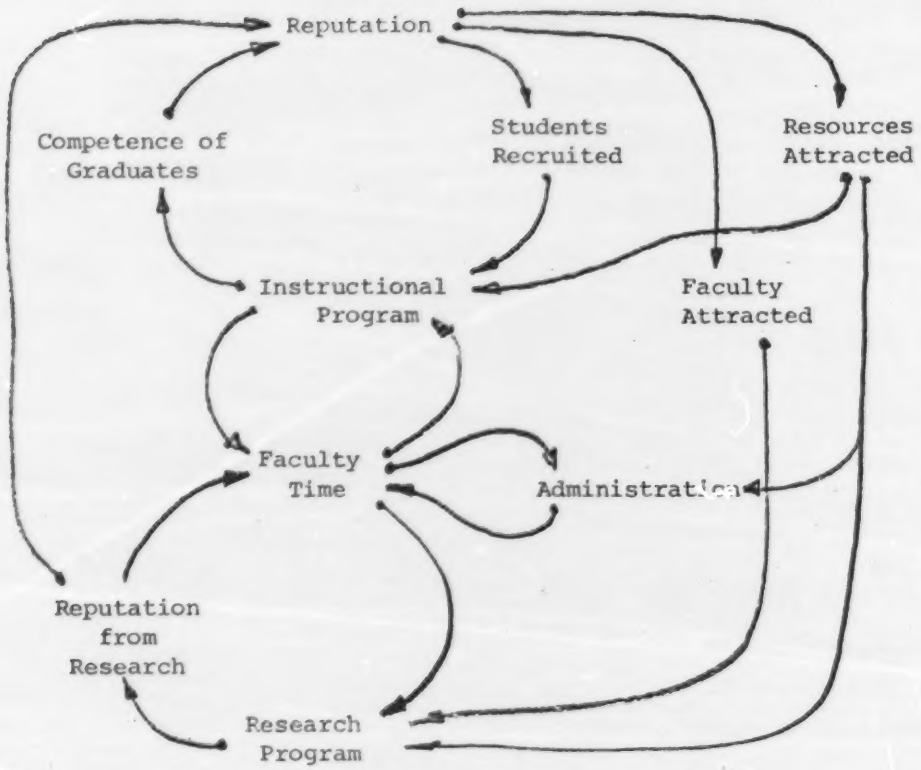


Fig. 13. A complex causal-loop diagram of the factors interacting within a college, relating the allocation of resources to the quality of programs.

f. This causal-loop diagram of the School was then used in two ways: (1) to give feedback to the participants and encourage them to explore the implications of this model, and (2) to provide the basis for a DYNAMIC model, such as will be discussed in Section 3.0. of this chapter. Unfortunately, time pressures acting upon the study team led to a reduction of their efforts on the earlier stages of this modeling procedure (the formulation and manipulation

of PROSE and STRUCTURAL models), and an overemphasis on the preparation of the DYNAMIC model. This unbalanced effort resulted in an excellent DYNAMIC model, but the participants were not sufficiently involved in the process to understand, accept and use it! This experience served to re-emphasize the importance of the overview of the entire modeling process as suggested by Fig. 1, and the dependence of each successive stage upon a thorough development and manipulation of the models in each of the earlier stages.

2.2.3. Advantages of this causal-loop approach are based upon its use of relatively common symbols (names and arrows) to represent some rather unusual and complex characteristics of a problematique (a problem embedded in a social environment). When used appropriately, and based upon a foundation of good model building at each of the earlier stages (see Fig. 1), the production of a balanced and symmetrical causal-loop diagram is often very satisfying to the participants, because it seems to express so much in such a compact and easily understood diagram.

2.2.4. Difficulties with this approach are the same as for the other techniques noted above, except that most people can interpret a well-laid-out causal-loop diagram more quickly and more completely than either a verbal description or a matrix. These basic difficulties are restated below, just as a continuing reminder of their potential influence:

a. Participant-centered difficulties associated with the personal, political and social characteristics of the participants. In some situations, it has even been apparent that a man's deep resonant voice or a woman's

personal charm have added undeserved weight to that person's suggestions.

b. Technique-centered difficulties associated with the trial-and-error nature of the process for constructing an easily understood and symmetrically balanced causal loop. This seems to require repeated trials and the ability to discard early efforts that may have led to satisfying results, in order to achieve an overall sense of flow and movement.

Further limitations of this approach and type of diagram include (a) its inability to identify and display time delays between actions and reactions, (b) its inability to examine and display the nature of relationship between action-cause and its reaction-effect, (c) its inability to specify the manner in which several "action-causes" combine when they act together on one "reaction-effect," and (d) the severe limitations of the number of factors and relationships that can be included in a single study or in one understandable diagram.

2.3.0. Manipulating STRUCTURAL Models. STRUCTURAL models can be manipulated in much the same way as PROSE models: different groups can be asked to prepare alternative STRUCTURES which can then be compared, and the basis for choosing among them can be developed.

A simple example of this kind of manipulation was demonstrated in a community's effort to improve relationships between the school system and the community. Because of some strong differences in the value systems of various groups, three different scenarios and causal-loop diagrams

were prepared: one by the administration of the school system, one by the dominant ethnic group in the community, and the third by the minority ethnic group. Each group had quite different perceptions of the goals for the school, the factors that interacted to move the overall community-school system toward these goals, and the criteria that should be used in making decisions on the allocation of the school's resources. Prior to the development of multiple models, each of the three groups felt wholly frustrated by the others' lack of understanding of the "true" situation. Thanks to the strong desire of the top school administrator for mutual understanding, the groups were able to develop and distribute their models, to try to understand the others' perceptions, and to work toward a set of policies on the allocation of the school's scarce resources that was at least partially acceptable to its model.

While it is possible to manipulate structural models to estimate the probable effect of changes in one part of the system upon other parts, this "manipulation" is a mental activity of the analyst. The structural model, itself, makes only minimum contributions to this process because it is "static" and cannot operate independently of the analyst to demonstrate the effect of changes upon its performance.

The final type of "models" to be considered in this chapter will focus on two types of "dynamic" models which <u>can</u> be set in motion and will <u>operate</u> on their own. The next (final) section of this chapter will describe and illustrate such dynamic models.

3.0. From STRUCTURE to DYNAMICS

Both PROSE and STRUCTURAL models are 'passive,' in the same sense that they cannot operate or act independently to demonstrate the effect of the system's elements and structure on its performance over repeated time periods. DYNAMIC models can be prepared and set into motion, in order to observe their performance over time. In the discussion that follows, two types of DYNAMIC models will be presented: (1) computer models which operate within a computer, and for which the computer can print out a record of its performance over as long a period of time as desired, and (2) human simulations in which individuals interact within prescribed roles and constraints in order to experience and demonstrate the effect of those roles and rules on their joint performances.

3.1.0. Computer Models. The essential characteristic of this modeling approach is the specification of the characteristics of a model with sufficient completeness and precision that the model will 'run' (operate) and display operation characteristics which duplicate (simulate) the performance of the problem situation (the problematique). An incomplete model will not run, thus demonstrating the presence of theoretical gaps which must be filled before the model is whole, internally consistent and balanced. An imprecise model cannot be 'understood' by the computer, thus demonstrating the need for unambiguous descriptions of the model's components and relationships.

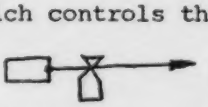
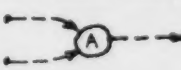
3.1.1. The technique will be described below, in terms of the specific actions taken to prepare a DYNAMIC model of the educational materials development center (EMDC) which was first presented in Sections 2.1.3. and 2.2.1.

a. A PROSE model was developed with the cooperation of the major decision makers who were concerned with the EMDC. Following the techniques suggested in Section 1.0., PROSE Models, a list of the significant factors involved and a description of their inter-relationships was prepared. (There are advantages as well as difficulties associated with moving either quickly or slowly through this PROSE model phase of a study. The rapid completion of these first steps can be encouraging to the participants, giving them a feeling of achievement and progress - but may yield relatively superficial results. The best compromise may be to take on a relatively small problem in the beginning, move quickly through all of the phases of modeling, and return to the earlier stages whenever necessary to achieve greater precision or more detail. This approach is consistent with the general modeling motto: START SMALL AND SIMPLE.)

b. The PROSE model was translated into a STRUCTURAL model. The Cross-impact matrix and Causal-loop diagrams suggested in Sections 2.1. and 2.2. were very useful in this process. These generalized forms needed to be refined into a special type of STRUCTURAL model as a step in the preparation of the computer statements which constituted the DYNAMIC model which the computer could interpret.

When modeling the EMDC (see Sections 2.1.3. and 2.2.1.), the causal loop diagram was expanded into a DYNAMIC model

which used the special computer 'language' of DYNAMO. This required the initial preparation of a STRUCTURAL model using the special symbols of the engineering field from which DYNAMO evolved. This is illustrated in Fig. 14, where the overall pattern of the causal loop (Fig. 10) is maintained, but the information is modified to show four types of quantities:

1. Conserved quantities, which tend to endure over time unless some of that factor either flows into or out of what is stored. Such a conserved quantity is shown in the diagram as a rectangle ( ).
2. Flows of the conserved quantities, which are represented as a valve which controls the rate of flow along a solid line ().
3. Information, which is represented by dotted lines showing that data about conditions in one element of the model are taken to another part of the model where they may be used to influence or control what is happening there ( ).
4. Auxiliaries, where information is combined in some way (such as adding or multiplying two pieces of information) and this new, combined information is used for control purposes ().

Knowing the meaning of these symbols may help in seeing the basic similarities between the two diagrams in Fig. 14.

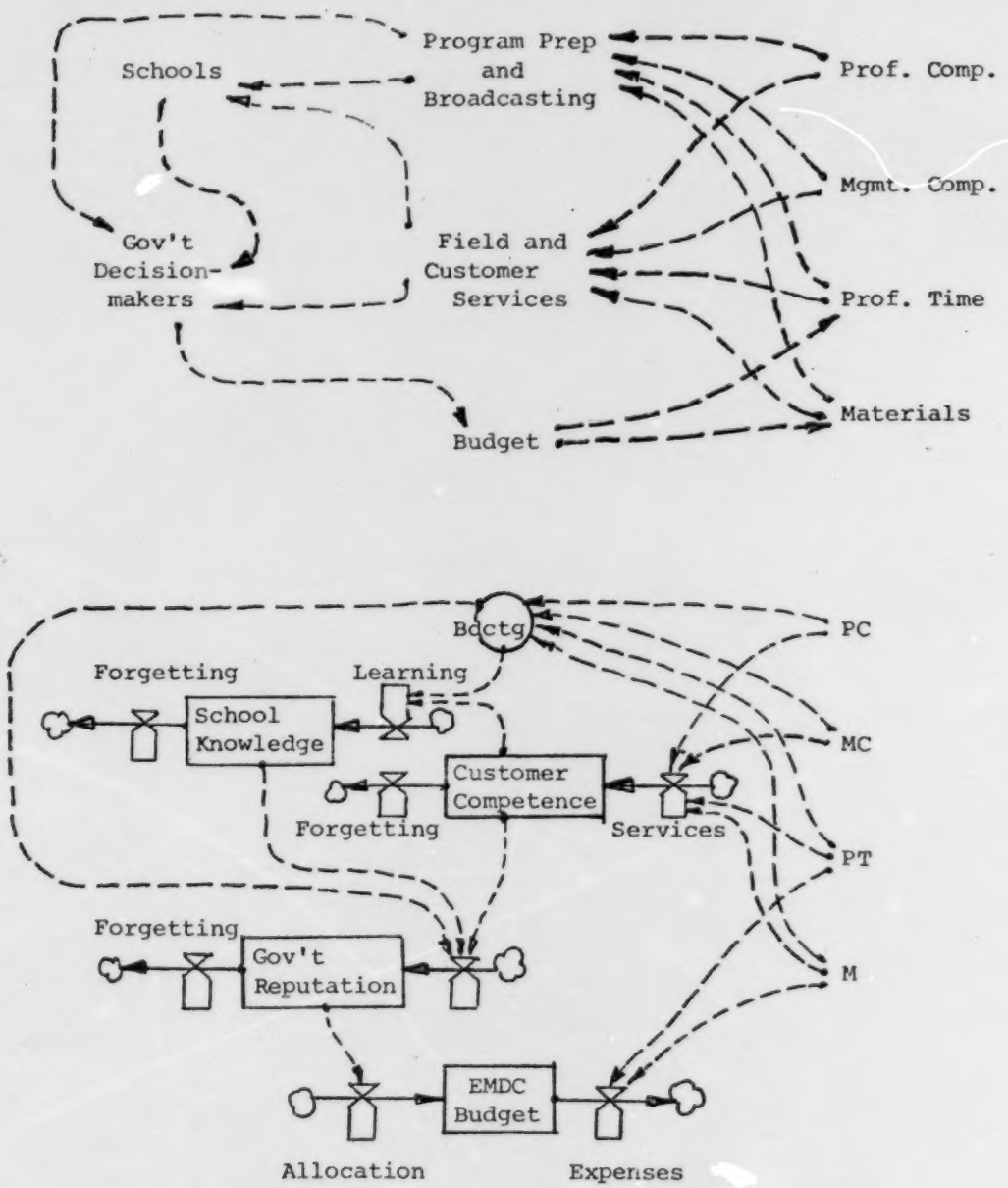


Fig. 14. Translating a causal-loop diagram into a STRUCTURAL model using DYNAMO symbols (simplified to illustrate only basic structure).

c. The information contained in the STRUCTURAL model was then expressed in a set of DYNAMO statements (using the special 'language' of DYNAMO which the computer can interpret.

d. The DYNAMO statements were entered into the appropriate computer, and the model was "run." While this is easy to say, it seldom happens quite this easily. Computers are very demanding aids, and must be given information in carefully thought-out and precisely stated form. Few of us who prepare computer models ever are able to write a good set of statements (the model) the first time we try. Usually, this process requires that we go back to the PROSE and STRUCTURAL models and refine them, before we are able to get the DYNAMIC model to perform the way we think it should, to represent (simulate) the behavior of the problem situation. But, often, the work and thinking required to prepare such a DYNAMIC model leads to new understanding (enriches our MENTAL models as suggested by line 9 on Fig.1), even before we manipulate the model.

e. When the basic DYNAMIC model performed adequately, it was manipulated in order to find the place (or places) where small changes would lead the model to perform in more desirable ways. In this way, several different but possible policies, decisions or actions were tested on the model to observe their effects on performance BEFORE those changes were applied to the real-world problematique. Experimenting with a good DYNAMIC model

is usually a much faster and cheaper way to test the probable impact of alternative decisions, than actually acting on them in the real-world and then trying to observe the effect of our decisions and actions.

3.1.2. An Example of a DYNAMO Computer Model. Building upon the PROSE and STRUCTURAL models that have already been presented, from the study of the Educational Materials Development Center (EMDC) in a Late Developing Country, this section will merely present and discuss the performance of that DYNAMIC model under three different conditions. It is also appropriate to indicate that the responsible decision makers in the EMDC have taken steps to change the EMDC in directions that tend to agree with the changes which produced desirable changes in the model.

First, the basic computer model (developed from the diagram in Fig. 14) was operated and found to lead to "failure." This can be seen in the diagram in Fig. 15 where the Reputation of the EMDC was slowly dropping and, the amount of money allocated to the Budget was gradually reduced by the government decision-makers until the EMDC was no longer able to continue operation. During the preparation of this basic model, it was found that approximately 95% of the total resources of the EMDC were devoted to the preparation and broadcasting of educational television programs, and only about 5% of the resources were allocated to customer and field services. It was agreed that the first changes in the model would focus on a redistribution of the resources between these two complementary functions.

Second, the same model was run with a different distribution of effort between broadcasting and service, and the computer results showed that the model's performance tended to stabilize, as shown in

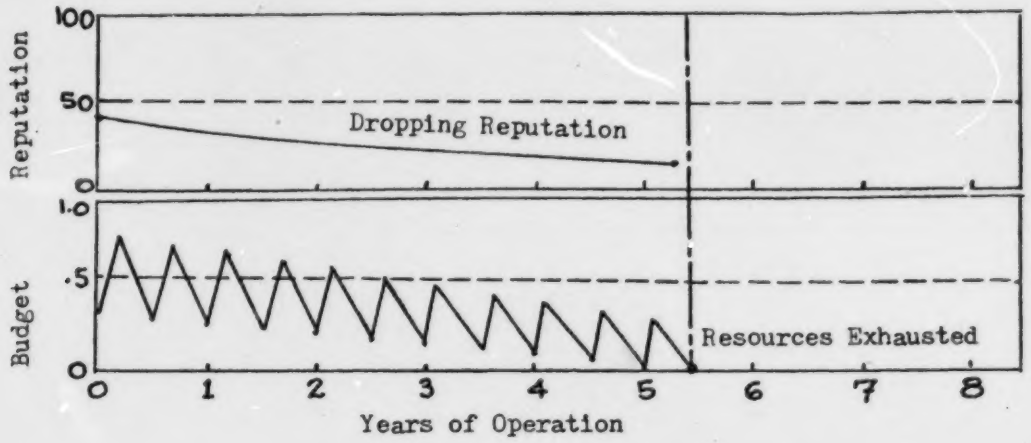


Fig. 15. The performance of a DYNAMIC model indicating the probable outcomes of present trends in an EMDC serving a developing country.

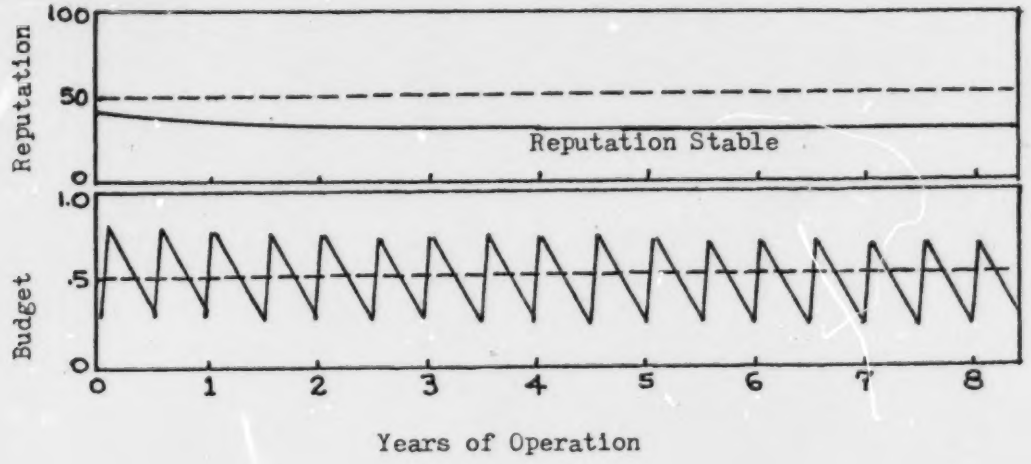


Fig. 16. The personnel in the EMDC were shifted to provide a 40% emphasis on customer services.

Fig. 16. Although this represented an improvement over the performance of the basic model, further modifications and manipulations were attempted.

Third, the effect of various types of education and training programs was explored, with small amounts of professional and managerial time being devoted to training. A combination of both changing the emphasis on broadcasting-vs-service and new training programs produced the dramatic effects indicated in Fig. 17, where both reputation and budget allocations rose significantly.

Further revisions in the model were proposed, because it was recognized that the initial model was VERY simple and had been developed VERY quickly by only a small group of people. But these further refinements were not made. The dramatic changes introduced into the EMDC during the months after the simple model was prepared, suggested that the very scarce planning resources should be directed at facilitating the changes that were being introduced, rather than investigating the possible effects of other innovations.

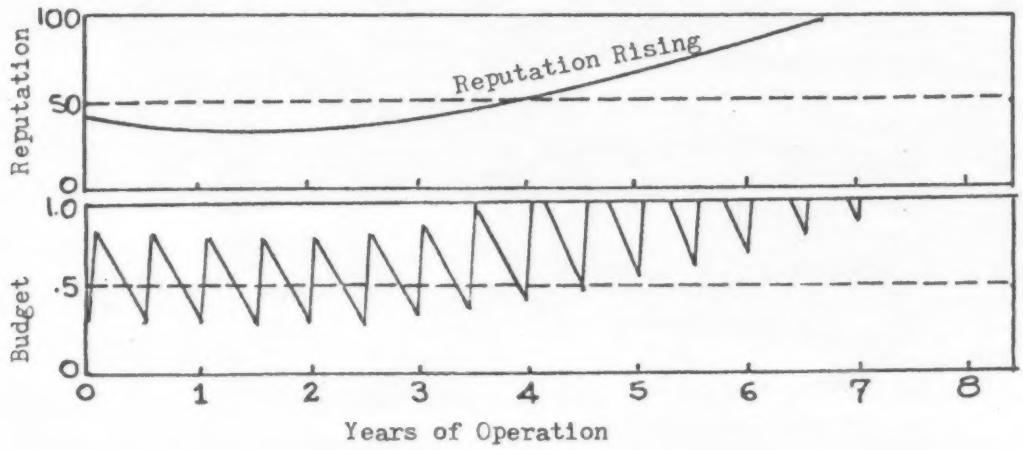


Fig. 17. The resources of the EMDC were reallocated to provide both (a) an increased emphasis on customer services and (b) increased education of both professional and management personnel.

3.1.3. Advantages of computer-based modeling arise from the extra-ordinary demands made upon the analyst-modeler and the participating decision-makers for completeness and precision. Many assumptions which were hidden during the preparation of the PROSE and STRUCTURAL models had to be made public and stated with precision. For example, it had been assumed that the EMDC contributed to student learning in the school through a combination of the materials delivered to the schools and the various kinds of services provided to the schools. But just HOW did those two complementary influences combine to produce their joint effect? Were they additive, with equal weighting? Did they combine multiplicatively, so that the absence of one would completely neutralize any contributions from the other? Although there was little "hard" data to guide anyone in making this modeling decision, it had to be made specific and precise in order to permit the model to demonstrate the implications of our perceptions. Out of this difficult, detailed exploration of one's perceptions and theories (beliefs about how people learn from different influences in their environments), came both a new respect for the complexity of the system with which we were working and a much clearer view of the probable impact of the everyday actions of the people within the EMDC. It was then quite apparent that the different groups of people simply MUST coordinate their actions in order that they impact together upon the schools and government decision-makers, for materials without training were worthless, just as training without appropriate instructional resources was also worthless.

3.1.2. Difficulties with this approach must be carefully considered and balanced against the possible benefits, before beginning a project to prepare a computer-based DYNAMIC model. These difficulties include:

a. Large and sophisticated computers are required, with the analyst/modeler having easy access to the machine and the special program needed to enable the computer to interpret DYNAMO statements. Although these are relatively common in large Universities, large business and government planning offices, they are not immediately available in every location (although recent advances in the use of remote terminals which can connect to computers over normal telephone lines are making them much more available).

b. Skilled personnel are relative scarce, who can prepare the required computer statements and interpret the computer print-outs. This difficulty is usually dealt with in one of three ways: by hiring a person with the skills and placing that person in a centralized planning unit; by sending a person from the planning unit to an appropriate center or university for training; or, asking a skilled consultant or university center to assist in the preparation and use of the model. None of these approaches should be taken without careful consideration of the alternatives, and the implications of each alternative.

c. Decision-makers' understanding of models and the meaning of data obtained from the models. DYNAMIC computer models have an aura of mystery and magic, which needs to be dealt with. The purpose of DYNAMIC models is to further enrich the MENTAL models of the responsible decision-makers

(see Fig. 1, again), and considerable exposure to these models and assistance in interpreting them is needed before they are really useful to decision-makers - but, the effort is well worth the trouble. It is generally recommended that the responsible persons be continuously involved in all of the steps indicated in Fig. 1, in order that all of these kinds of models serve their intended purposes.

3.2.0. Human Simulations. The essential characteristics of this approach to modeling is the involvement of people in a simplified and simulated situation where they can experience the effect of carefully designed roles and rules over relatively short periods of time. This technique is deliberately presented as the last modeling approach in this chapter because it is recommended as one of the final steps in any modeling effort. The responsible decision-makers need to personally experience the scenarios, structures, and dynamics which have grown out of their thoughts and perceptions, but which also need to be experienced (with appropriate thinking, feeling and acting) in order to develop the richest possible insight or MENTAL model of the problematique.

3.2.1. The technique will be described below in very brief form, and will be illustrated, later in Section 3.2.3.

a. An elaborate PROSE model should be developed, describing the groups and individuals who are involved in or influenced the problematique. Initial efforts in constructing a PROSE model may deal with a selected number of decision-makers or knowledgeable persons, but later efforts should lead to field interviews and

observations by the analysts/modelers in order to get a full sense of the complexities in the situation.

b. A STRUCTURAL model should be constructed in order to simplify and organize the basic factors identified and described in the PROSE models. This organized insight is an important foundation for the construction of an appropriate and effective simulation, and inadequacies at this point may be seriously limiting, later.

c. A DYNAMIC computer model should be developed and operated - even a very simple one - in order to gain assurance that the model being developed has the potential for describing and explaining the most important behaviors of the problematique. This step is very seldom taken. Most simulations are designed and played by persons who are seeking some form of general education, rather than seeking to understand and take action to change some social problem. Here, we are not primarily concerned with educational goals and the means to achieve them, but rather, we are focusing on aids to decision-making relative to serious social problems. From this point of view, the preparation of a DYNAMIC computer model can provide additional data to support the validity of the conceptual base on which the human simulation is to be built.

d. The roles and rules for the simulation, and all of the supporting materials, facilities and personnel, are then specified. This is the stage of simulation design;

and there is a delightful mixture of science and art, of discipline and drama, involved in the design of a simulation. An effective background for those who design simulations includes varied experience with different kinds of simulations prepared by others, exposure to the writings of those who have studied and taught simulation, modest skill in writing, a controlled flair for the dramatic, and a willingness to prepare something, to try it out on a group of people, and to modify it until it simulates the critical characteristics of the problematique. In this way, a simulation is the same as a computer model because both must be tested and revised until they perform appropriately. Some specific suggestions on the design of a simulation would include the following:

1. Identify the key agencies and persons within each agency, carefully describe the actions which each agency and person take with respect to the problem, and write each set of actions in a separate "Job Description" to be given as a role prescription to each person in the simulation.
2. Identify the important resources and limitations within which each agency and person must act, if they are to experience the same types of environmental features in the simulation as in real-life. Describe these in a scenario for each player, and provide the resources and restrictions as part of the environment of the simulation.

3. Prepare a "Simulation Leader's Guide" defining very carefully the actions the leader must take to begin the simulation, to guide it through its various stages, and to bring the people together at the end to (a) examine their own behaviors during the simulation, and (b) make suggestions for making the simulation more realistic.

e. Alternative sets of roles, rules and environmental resources and constraints can then be designed into subsequent simulations to experiment with the effect of alternative DYNAMIC models (other systems structures) on the performance of the individuals and the entire system. During these manipulations of the model, it will be important to make measurements of the critical behaviors so that the differences introduced by changing roles and rules can be evaluated.

3.2.2. An Example of a DYNAMIC Simulation Model. The national agency concerned with the education of handicapped children had supported the development of a network of agencies to conduct research, develop and distribute educational materials which had been shown to be effective with specific types of handicaps, and train teachers to use these materials and appropriate methods with particular children. Unfortunately, this network was not as effective as had been hoped, as indicated by the small number of materials and methods that were actually reaching the teachers in their classrooms.

In an effort to understand the dynamics of this system, as one step toward its improvement, a simulation model of this network was prepared. The key persons in the network were interviewed, the designer/

consultant visited typical agencies throughout the network, and preliminary versions of the simulation were tested on persons who were both uninformed about the network as well as others who were intimately familiar with it. Each participant was assigned to one of the typical agencies in the network:

- The National Bureau for the Handicapped;
- A university research and development center;
- The National Professional Agency for Educators of the Handicapped;
- Regional Centers of the distribution of materials and the training of teachers;
- Publishers of the educational materials;
- The public schools (state as well as municipal) in which handicapped children were educated.

Each participant was given a notebook which provided the background for the simulation (the Scenario developed early in the design process). The individual was assigned a specific title and role, with a number of required, permitted and forbidden actions. Physical facilities were arranged to simulate the difficulties associated with travel from one agency to another. Communications between persons and agencies were controlled. Tight time schedules were imposed for the completion of simulated tasks. Unexpected emergencies were introduced into the simulation at irregular intervals. Simulated money was provided, simulated materials were developed and sold with the hopes that they would eventually reach the teachers, and certificates were awarded those who attended special skill training sessions. At the end of the simulation (after a full day of interaction), the behaviors of the participants was examined and the number of simulated materials and

certificates for the acquisition of new skills, counted. It was generally agreed that the simulation replicated the critical performances of the real-world situation; everyone was VERY busy and VERY emotionally involved, BUT almost no materials and skills filtered down to the teachers! In the post-simulation discussion, many suggestions were made on changes that might be made in both the model and in the real network.

The simulation was then modified to produce three different versions, each representing a different proposal for the improvement of the network's performance: improved communication among the agencies; a Network coordinator with responsibility to keep track of the flow of materials and skills, and the authority to expedite their movement; and a combination of both improved communication and a Network Coordinator. Each version of the simulation was conducted with groups of educators - BUT, unfortunately, the types of persons involved changed drastically between the successive simulations and the highest level policy-makers were transferred to other projects or were distracted to other tasks and, therefore, the final assessments were inconclusive about the effect of the different model structures on the simulation's performance (because too many other things had also changed).

This experience appeared to demonstrate that such simulations can be developed and conducted for the analysis of large and complex social problems, but that these activities require the continuing interest and support of the responsible persons.

3.2.3. Advantages of human simulation as DYNAMIC models come primarily from the effect of this experience upon those who become

involved in it. Participating in a simulation is a vigorous and stimulating activity. When adequate preparation has been made (the participants come to the experience prepared, and are given a good introduction to the procedures and purposes), the experiences can stimulate a high level of motivation. During one experience with the simulation model described in Section 3.2.2. (the Network of Centers for the Handicapped), the 35 participants became so involved with the experience that they would not stop after eight hours, but insisted upon continuing another two hours in order to see if they could achieve the goals they had set for themselves!

A second advantage that can come from a simulation arises out of the post-simulation discussion. Having experienced the impact of the simulation's rules and constraints on their progress toward the system's goals, the participants often come to new insights about ways to improve both the simulation model and the real situation that lay behind the model. This kind of a discussion acts as both a training device for the participants and a "laboratory" from which both the analyst/modeler and the decision-maker can learn.

Both of these advantages (motivational and educational) can be achieved in a very short period of time (a simulation usually lasts no more than a few hours - from 2-36 hours) with an apparently small investment (only the paper needed to define each participant's role, and the minimum resources of a room and a few "things" which are manipulated during the simulation). BUT . . . BUT . . . BUT . . . this simplicity tends to hide the long and demanding preparation that should come before the simulation (although some people don't go through all the modeling stages that have been described and recommended here).

Perhaps the most important advantage of a human simulation after all of the other kinds of models have been prepared and manipulated, is the validation that a group of knowledgeable and experienced persons can provide through participating in one or more simulations which demonstrate the characteristics and implications of various models of some problematique in which they, themselves, are involved. For example, the managers of the EMDC (see Sections 2.1.2. and 2.2.1.) could have been asked to participate in a human simulation of the three different structures which evolved from that study: the basic model of the structure that led to the simulated collapse of the EMDC, the model with a balanced effort between production and service, and the model which combined the production-service balance and the educational programs. Their response could have indicated that the basic model was a realistic representation of the actual system in which they were daily involved - and the model could have been adjusted until that support was given. They could then have participated in testing the validity of each proposed change in the model. In the process, they might have learned a great deal about their own system, and might be emotionally prepared for the changes in responsibilities resulting from top management decisions to implement these new policies.

3.2.4. Difficulties encountered in designing and conducting DYNAMIC human simulations would include:

a. The special skills needed to design and conduct this kind of a group experience so that it is both meaningful to the participants and valid as a model of the problematique it is intended to simulate. Such skills are not common. Many designers of educational simulation-games would

have relevant skills, but the two tasks are not exactly the same; the designer of this kind of a DYNAMIC model would need the skills necessary to design and analyze the earlier kinds of models that should precede the analysis of this more complex model.

b. The decision-makers' time and attention may be difficult to obtain. The most successful simulations of this type have been conducted when the highest levels of policy-makers are strongly interested and also wish to involve the other key persons in the system.

c. The evaluation of the initial problematique, and then the conduct of related evaluations before, during and after the simulation, can be a difficulty. Special skills are needed to conduct such careful evaluations in both real and simulated conditions. It is possible and desirable to obtain such skills either through (1) hiring persons with these skills, (2) sending individuals from a Planning Unit away to acquire these skills, or (3) employing agencies or consultants to provide these competencies as they are needed.

3.3.0. Manipulating a DYNAMIC Model. Several examples have already been given of ways to manipulate the DYNAMIC models which have been described in the earlier sections. The essential characteristics of these manipulations have been:

a. Sensitivity analysis, or the effort to find the one or more places in a model where small changes are likely, in the long run, to result in desired changes throughout

the entire network or problematique. A computer-based model is an ideal mechanism for a sensitivity analysis, because successive runs of a computer model can be achieved quickly and inexpensively (although finding the best places to make such changes, and determining the direction and magnitude of those changes, is neither easy nor inexpensive in terms of the mental effort of the participants).

b. Structural analysis, or the exploration of the performance of alternative models of the same problematique. This kind of analysis goes beyond a "sensitivity" analysis which considers the effect of small changes within the same structure, and tries to examine the effect of changes in the structure itself.

And, as has been suggested repeatedly in these pages, the purpose of all of these manipulations is the enrichment of the MENTAL models of the decision-makers who are responsible for the policies, decisions and actions which will, eventually, impact upon the real-life problematique. Their involvement in these activities will be a critical factor influencing their willingness to act upon the outcomes of any modeling effort.

4.0. Summary and Conclusions

Social problems are normally embedded in complex environments within which a large number of factors interact to influence the behavior of the components of the system (the problem as well as the desired outcomes) and the overall system itself. The complexities involved are usually beyond the capabilities of the human mind to understand in sufficient detail and precision, so that correct actions have a high probability of being effective. Three different types of models can provide significant assistance to human decision-makers, as they attempt to set policies, make decisions and take actions to solve problems and improve situations. These types of models are:

** PROSE models, which use words (written or spoken) to express one's understanding of the factors and relationships which influence the problem,

** STRUCTURAL models, which build upon the PROSE models and represent the system's components and relationships in the form of diagrams or other non-verbal symbols, and

** DYNAMIC models, which build upon the STRUCTURAL models to achieve an operating, performing model that demonstrates the critical behaviors of the problem situation.

Each of these types of models has strengths and limitations, and requires particular skills to prepare, conduct and analyze. But the position is taken here that the social problems faced by individuals, organizations and nations are sufficiently important and complex that both the time and skills required to prepare and use models can be justified. Those who acquire and use these new ways of approaching and understanding problems and social systems can make increasingly significant contributions to their countries and cultures.